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MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING
PROGRAM QUARTERLY TECHNICAL REPORT

Contract Number DAAB07-76-C-8135

LIGHT EMITTING DIODES FOR FIBER OPTIC COMMUNICATIONS

Prepared By:

LASER DIODE LABORATORIES, INC.
205 Forrest Street
Metuchen, New Jersey 08840

Sixth and Seventh Quarterly Reports
for the Period 1 January 1978 to 30 June 1978

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Placed By:

U. S. Army Electronic Research and Dvelopment Command
Fort Monmouth, N. J. 07703

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Prepared by:

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Product Development Manager

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The design and fabrication of high speed etched-well light emitting diodes for fiber optic communications is discussed with regard to materials synthesis via LPE, wafer fabrication, and device assembly in a manufacturing environment.

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SECTION I

INTRODUCTION

The primary objective of this Manufacturing Methods and Technology Engineering Program is twofold. First, the manufacturing methods and techniques necessary for the volume production of the light emitting diode for use in fiber optic communications as outlined in Specification SCS-511 must be developed and implemented to insure the highest degree of device quality and reliability at a reasonable cost. Secondly, verification of device performance and quality for LED's produced in a volume manufacturing environment must be carried out by means of rigorous testing and evaluation in accordance with SCS-511 in order to demonstrate the technical adequacy of the manufacturing methods developed under this contract.

The major objectives for the sixth and seventh quarters of the program include SEM analysis of zinc diffused wafers with attendant process change to control the diffusion, fabrication of devices with the new ITT GG-02-8, measurement of P_O with this fiber versus fiber epoxying methods, delivery of the third engineering sample with this fiber, and the start of the 2000 hour operating life as the fourth engineering sample.

SECTION II

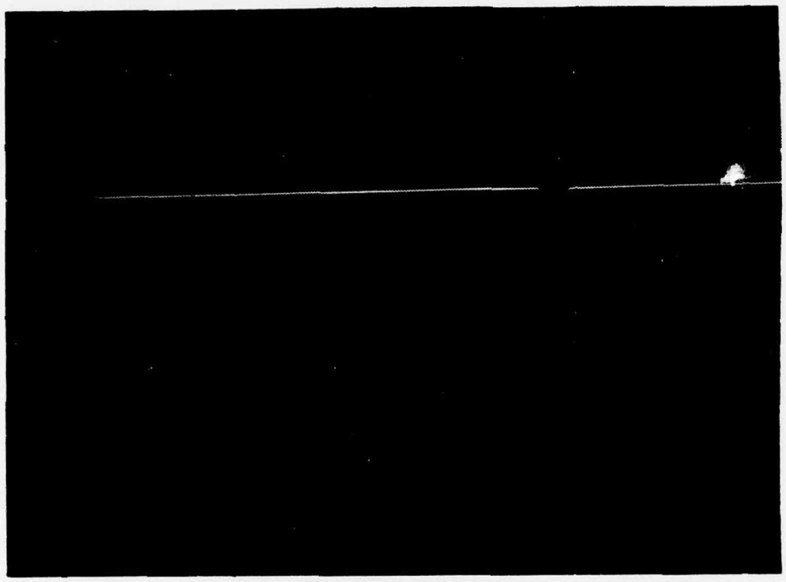
MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING

2.1 Wafer Processing for Etched Well Light Emitting Diode Chip Fabrication.

Analysis of defective zinc diffused wafers has been made possible by the aquisition of a Scanning Electron Microscope. In order to establish a base line for proper interpretation of the SEM photographs, a test wafer was zinc diffused producing a p-n-p structure. Figure 1 is a scan on the test wafer. The scan direction is from left to right. The first induced current wave-form upward indicates a p to n transition. The current peaks at the p-n junction, and then falls to a constant level in the n substrate layer. The next induced current waveform downward indicates an n to p transition, with the indicated peak at the n-p junction, and a fall to a constant level in the p layer. Figure 2 is an SEM scan of a defective wafer. The straight line indicates the exact scan location. The solitary induced current waveform upward p to n transition indicates that the n blocking layer has been "washed out" or converted to 'p' type material. Figure 3 depicts the proper device structure before (A) and after (B) the zinc diffusion. As a consequence of this information it has been determined that the n blocking layer was too lightly doped and thus easily converted to p type material. Increased doping

SCAN DIRECTION

'p' to 'n'



'n' to 'p'

Figure 1. SEM Scan of Zinc Diffused Test Wafer.

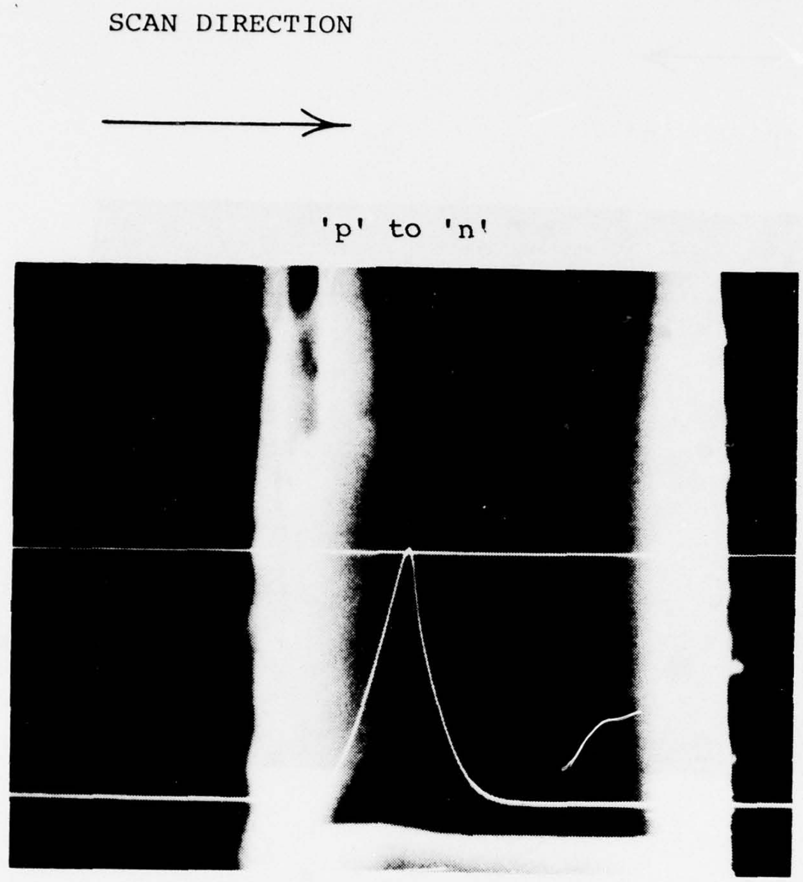


Figure 2. SEM Scan of Defective LED Wafer.

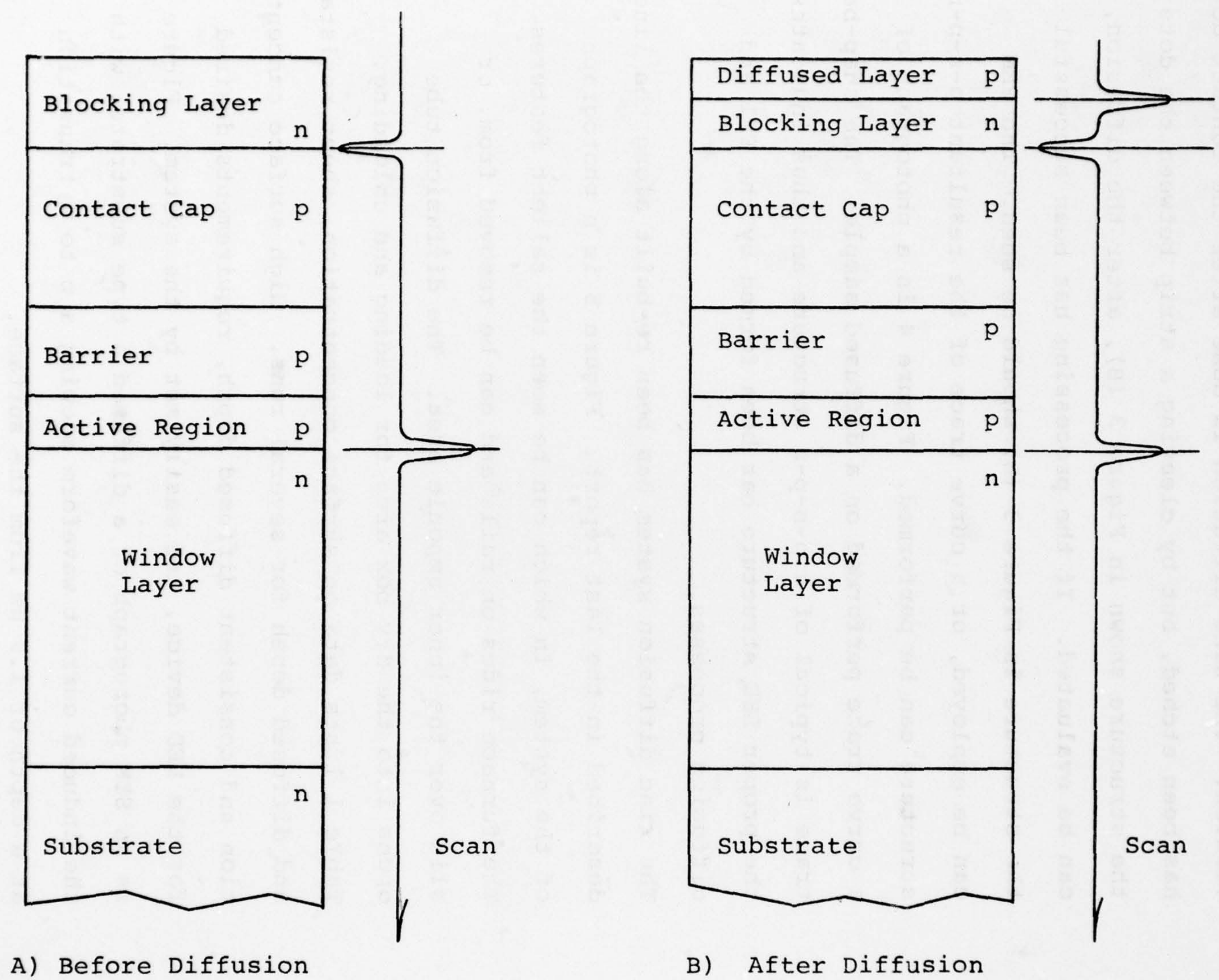


Figure 3. SEM Scan EPI Structure.

of this layer in the EPI processing will prevent this conversion. The zinc diffusion is done after the contact dot has been etched, but by cleaving a strip between the dots the structure shown in Figure 3 (B), after the diffusion, can be evaluated. If the processing has been successful the structure in Figure 3 (B) should be seen. The SEM can be employed, or a curve trace of the resultant p-n-p-n structure can be performed. Figure 4 is a photograph of a curve trace performed on a diffused sample. The snap-back trace is typical of a p-n-p-n structure and thus indicates the proper LED structure has been formed by the EPI and diffusion processes.

The zinc diffusion system has been re-built along the lines described in the last report. Figure 5 is a photograph of the system, in which can be seen the salient features. The furnace rides on rails and can be removed from, or slid over the inner ampoule area. The diffusion tube opens into the dry box area for loading and unloading. Table 1 lists data on surface concentration, sheet resistance and diffused depth for several runs. High surface concentration and consistent diffused depth, requirements desired for the LED device, are easily met by the system. Figure 6 is an SEM photograph of a diffused n type substrate, with the induced current waveform showing a p to n transition at a depth of 1.9 μm from the surface.

2.3 Diode Assembly Techniques

After discussions with ECOM personnel, agreement has been reached concerning upgrading of the contract, by

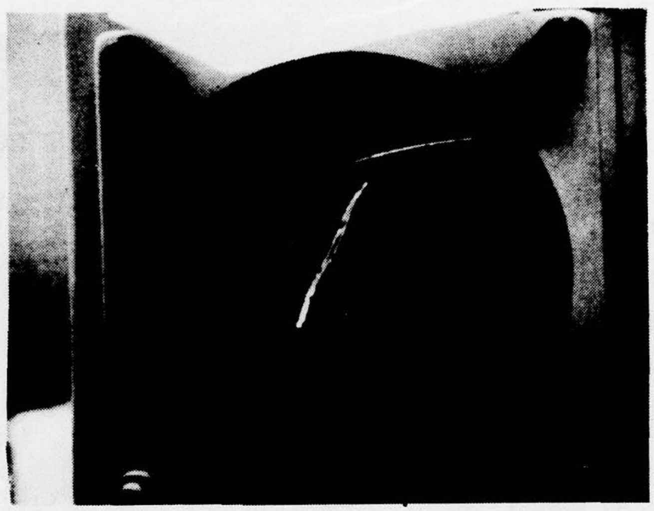


Figure 4. Curve Trace of Biased p-n-p-n Structure.

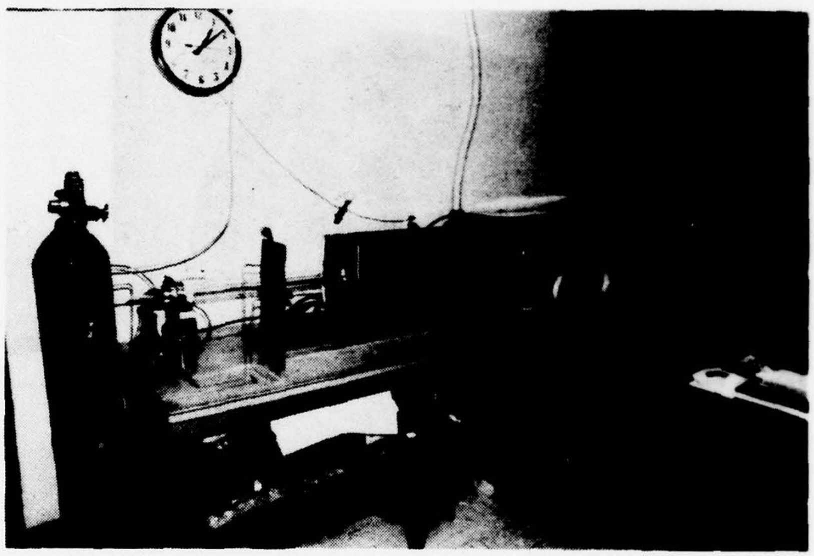


Figure 5. Zinc Diffusion Furnace.

TABLE I. ZINC DIFFUSION DATA

		Surface Conc. 10^{18} AT/cm^2		Resistivity 10^{-3} Ω-cm			Surface Conc. 10^{20} At/cm^2		Resistivity 10^{-3} Ω-cm		Diffused Depth μm		
		BEFORE DIFFUSION					AFTER DIFFUSION						
DATE													
TIME													
1		3.3		1.1			4.96		1.19		1.90		
2		5.1		0.9			4.8		1.2		1.95		
3		4.7		0.9			6.28		1.57		2.00		
4		5.2		0.8			5.4		1.36		1.90		
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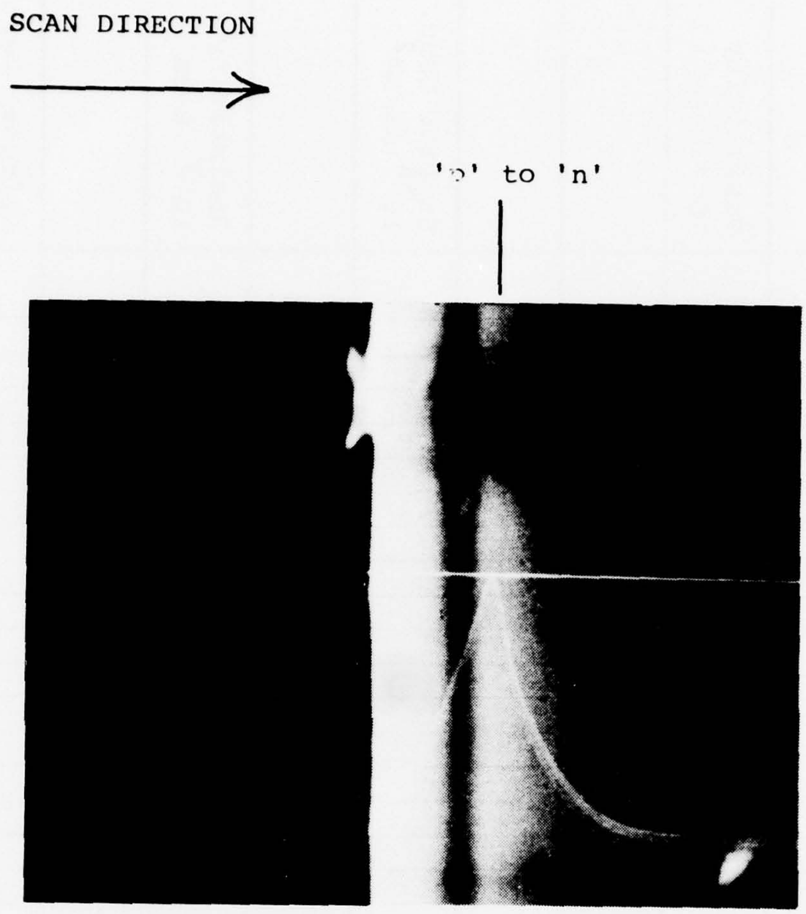

Figure 6. S.E.M. Scan of Zinc Diffused Substrate.

a substitution of the ITT GG-02-8 fiber for the Galileo Galite 4000 fiber originally specifed. This program upgrading will result in a superior fiber optic pigtailed light emitting diode for Communication Applications with LED pigtail to fiber optic cable interface that is currently considered both state of the art and best production interface for existing ECOM system requirements. Figure 7 shows an LED fabricated with the new fiber which illustrates the extreme flexibility of the fiber. Table II is a list of changes required in SCS-511 to reflect the effects of the fiber change. Figure 8 shows two ways in which the fiber can be epoxied to the ferrule. Because the core is small relative to the fiber diameter, considerable optical power can be coupled into the cladding and the optical power out of the pigtail is affected by the way the fiber is epoxied to the ferrule. Results of the two epoxying methods are discussed in section 2.4, Device Evaluation and Testing.

The chip soldering fixture described in the last report has been completed and is shown in Figure 9. The fixture body is graphite, or in the chip and solder preform locating ring. The weight is polished stainless steel and is sized to allow a sliding fit in the locating ring. An eight minute cycle time has been established in the GCA Infra-red belt furnace to solder a fixture loaded with twenty-five units.

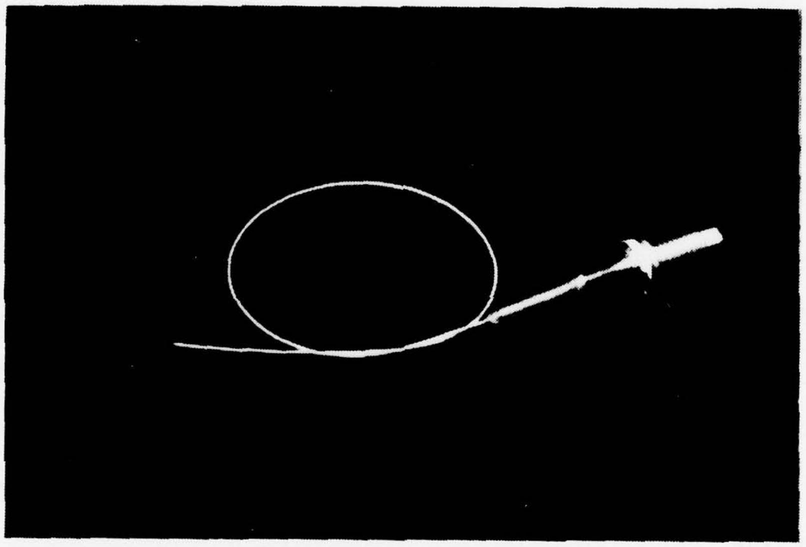

Figure 7. LED With ITT Fiber.

TABLE II. SCS-511 Amendment II

1. TABLE III

   A. Subgroup 2

Output Optical Power	.100 mw min.

2. TABLE VI FIBER CHARACTERISTICS

Core Diameter	55 μm nom. 62.5 μm max.
Cladding Diameter	125 μm nom.
Protective Jacket Diameter	500 μm nom.
Bending Radius	5 mm nom.

3. FIGURE 1 PHYSICAL DIMENSIONS

   Change fiber detail drawing to reflect TABLE VI changes.

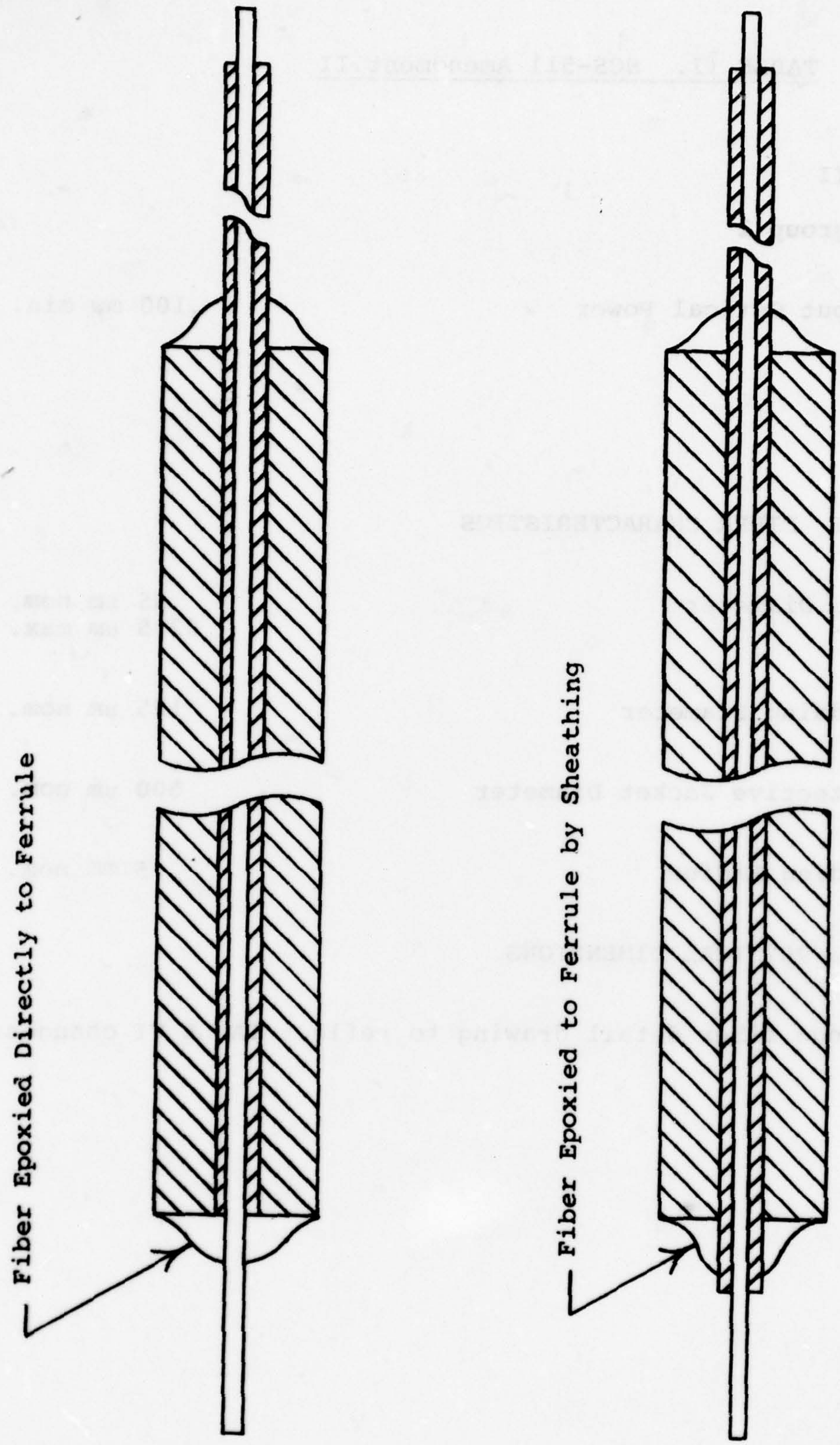

Figure 8. Fiber Epoxied to Ferrule.

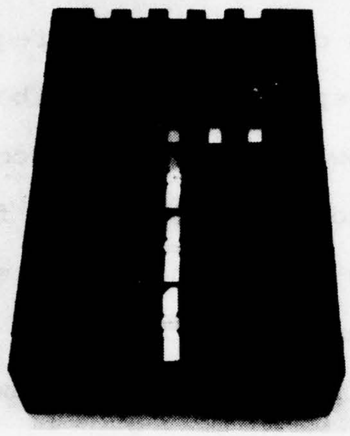

Figure 9. Chip Soldering Fixture.

2.4 Device Evaluation and Testing

2.4.1 Device Evaluation

The new fiber, ITT GG-02-08, with its small core and large cladding to core area ratio required evaluation of the affect of epoxying of the fiber to the ferrule on the optical power that could be coupled out of the LED. Referring to Figure 8, if the fiber is epoxied to the ferrule by contacting the integral sheathing, then the full diameter of the fiber, including core and cladding, will couple optical power into the fiber. When the fiber is epoxied to the ferrule by contacting the fiber itself, any power into the cladding is stripped out by the epoxy coupling and only that power accepted by the core will be propagated down the fiber as usefull optical power output. Calculations based on the ratio of the cladding to core areas indicates that a loss on the order of 6 db can be expected when epoxying directly to the fiber. Table III contains data on lot Bur-B-72 which was used to ascertain the results of the two methods of epoxying the fiber to the ferrule. Calculations based on the data in the table indicate there is a loss on the order of 4 db in the direct epoxying method. It is possible to partially epoxy the fiber to the ferrule when attempting to epoxy to the sheathing only. In this case a partial coupling of optical power out of the cladding will occur and intermediate optical power out of the fiber will

TABLE III. LOT BUR-B-72 GG-02-08 FIBER

DATE													
TIME													
#													
1		.450											
2		.430											
3		.565		BARE DIODES									
4		.430											
5		.510											
1		.410											
2		.400		FIBER EPOXIED TO FERRULE BY									
3		.450		OUTER SHEATHING									
4		.400											
5		.450											
1		.110		FIBER EPOXIED TO FERRULE									
2		.120		DIRECTLY									
3		.200											
4		.180											
5		.190											
INSP. BY													

be obtained. This condition is illustrated in the data of Table IV, where microscope examination of the units revealed varying degrees of partial epoxying. Table V contains data on units which will be supplied as the third engineering sample with the ITT GG-02-8 fiber. The variation in the optical power output is, again, due to partial epoxy coupling as described above.

2.5 Test Equipment

2.5.1 Life Testing

A 4th Engineering Sample of 16 units fabricated with the ITT GG-02-8 fiber was assembled and placed on a 2000 hour operating life test. The devices are run at a constant current of 100 ma. Table VI contains P_o data at 0 hours, 176 hours and 1008 hours, the total time completed for this report period. Calculations show that, on the average, the change in P_o is less than 1% per 1000 hours. The 2000 hour life test will terminate in mid-August.

TABLE IV. LOT BUR-B-72 GG-02-08 FIBER

		P_o (mw) @ 100 ma BARE DIODE		P_o (mw) @ 100 ma FIBER COUPLED									
DATE													
TIME													
#													
1		.400		.120									
2		.430		.320									
3		.450		.400									
4		.400		.100									
5		.450		.380									
6		.410		.110									
7		.400		.180									
8		.390		.240									
9		.450		.170									
10		.410		.315									
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TABLE V. 3RD ENGINEERING SAMPLE - ITT GG-02-8 FIBER

		P_o (mw) @ 100 ma		λp (nm)		V_f (volts) @ 20 ma							
DATE													
TIME													
#													
1		.106		813		1.4							
2		.120		826		1.3							
3		.210		830		1.4							
4		.200		830		1.3							
5		.187		823		1.4							
6		.240		830		1.4							
7		.145		830		1.3							
8		.310		800		1.4							
9		.314		800		1.4							
10		.313		802		1.4							
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LOT BUR-B-72

TABLE VI. 4TH ENGINEERING SAMPLE 2000 HR LIFE

		P_o (mw) @ 100 ma T = 0 Hrs.		P_o (mw) @ 100 ma T = 176 Hrs.		P_o (mw) @ 100 ma T = 1008 Hrs.							
DATE TIME													
1		.300		.305		.303							
2		.195		.185		.185							
3		.315		.320		.317							
4		.316		.310		.311							
5		.436		.436		.432							
6		.352		.340		.340							
7		.247		.242		.245							
8		.429		.425		.423							
9		.329		.320		.322							
10		.385		.385		.385							
11		.365		.365		.363							
12		.430		.425		.425							
13		.331		.327		.327							
14		.240		.242		.243							
15		.310		.309		.310							
16		.410		.404		.412							
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SECTION III

SUMMARY AND CONCLUSIONS

During the sixth and seventh quarters, by means of SEM analysis, corrections were made in the blocking layer EPI step to prevent subsequent zinc diffusion from 'washing' out the layer. The zinc diffusion system was rebuilt to improve repeatability. A third Engineering Sample was supplied with the ITT GG-02-8 fiber and a fourth Engineering Sample with the ITT GG-02-8 fiber was started on a 2000 hour operating life test. Plans for the next quarter include continuation of zinc diffusion tests to establish conditions for shallow diffusions, on the order of 0.5 μm, the accumulation of data on devices with the ITT GG-02-8 fiber with and without epoxy de-coupling, completion and delivery of the fourth Engineering Sample 2000 hour operating life test units, and completion of a test plan which meets the requirements of SCS-511.

APPENDIX A

Engineering Man-Hour Utilization for the
Sixth and Seventh Quarters of the Program.

	6th Qtr.	7th Qtr.	Cummulative
R. B. Gill	6 Hrs.	12 Hrs.	46 Hrs.
A. Gennaro	124 Hrs.	128 Hrs.	1065 Hrs.
M. Lai	16 Hrs.	-	281 Hrs.
P. Schneider	2 Hrs.	-	2 Hrs.
S. Klunk	2 Hrs.	-	2 Hrs.
T. E. Stockton	-	-	472 Hrs.
R. E. Albano	-	-	248 Hrs.
Manufacturing Personnel	574 Hrs.	391.5 Hrs	3469.5 Hrs.

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